8 ATTACHMENT IV — BLIP RASTER SYSTEM AIP

Revision	Affected Pages	Effective Date
0	entire attachment	Sep-13

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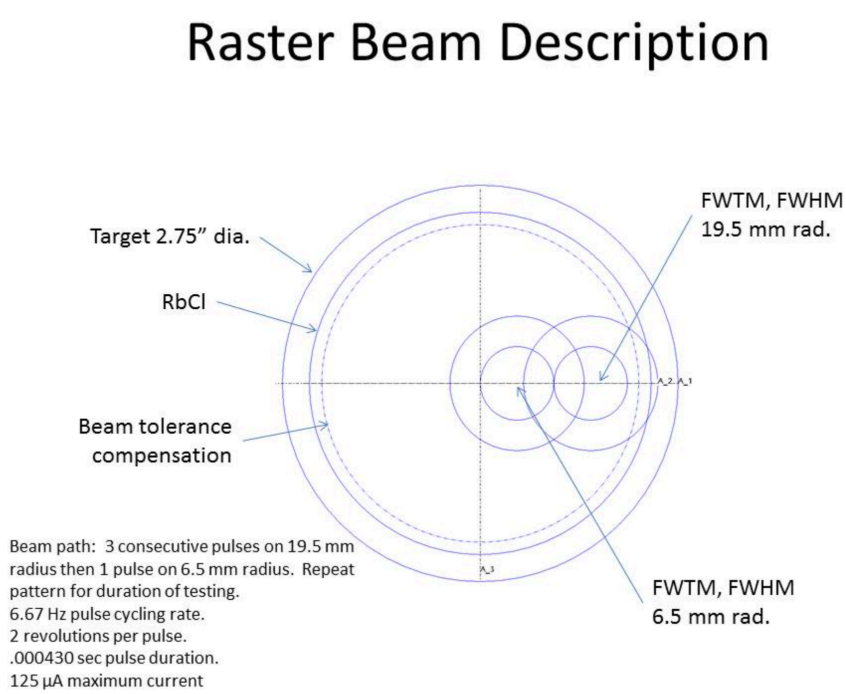
Project Description

The two most important isotopes produced at Brookhaven Linac Isotope Producer (BLIP) are Sr-82 and Ge-68, and demand currently exceeds our capacity. All else staying constant, increased beam intensity directly makes more product. Efforts to improve supply with increased intensity have been difficult. The Linac has succeeded in increasing the maximum beam current to BLIP to 125 μA and an average beam intensity of 110 μA has been achieved. The beam is pulsed and the instantaneous beam current can be as high as 43 mA. Combined with a sharply peaked Gaussian-shaped beam intensity profile this creates very high power density at the beam spot center (>4 kW/cm^2) and has caused target reliability and lifetime issues due to overheating, as well as somewhat erratic isotope yields. The short term response has been to limit Linac intensity to no more than 105 μA. There is a better way. We propose to implement the design and installation of a beam raster system in BLIP with a rapid (5 kHz) scan frequency. Three consecutive beam pulses will be rotated in a circle of diameter 19.5mm radius, then one beam pulse will be rotated in a circle of diameter 6.5mm radius. This pattern will be repeated so that a nearly uniform beam intensity profile can be achieved. In this manner the beam will complete 2.25 rotations per beam pulse of 450 μs length and the power density is reduced by at least a factor of four. This will increase isotope yield and sharply reduce target fatigue.



Sr-82 is created by irradiating RbCl pressed pellet targets. RbCl has poor thermal conductivity, and with the existing fixed Gaussian beam spot the salt melts only in the beam strike area. Upon melting the RbCl expands 21% and moves outward, refreezing into void space on the target's periphery, and reducing the amount of RbCl remaining in the irradiation zone by an estimated 10%. This effect also shifts the proton energy on downstream targets higher than optimum leading to reduced and variable Sr-82 yield.

The net impact on yield is as much as 20%, which roughly equates to $100k-$130k isotope revenue per month. The raster parameters, 5 kHz sweep with dual radius, are driven by the thermal properties of RbCl. In addition the raster will minimize material creep as most of the target will be consistently molten, but with lower overall temperatures than at present. The lower average salt temperatures can, in principle, allow safe increases in beam current up to 240 μA, enabling target survival if a future project to double the Linac beam intensity is approved and implemented. This compares favorably to the present maximum integrated beam intensity of 250 μA at the Isotope Production Facility at LANL where a raster system has already been implemented.

By spreading out the power density, a raster system will be beneficial for all targets by improving reliability. In 2011 and 2012 the Ge-68 target failure rate due to target leaks at high temperature was an unacceptable 50%. The program costs for replacement fabrication were approximately $65K, and the lost potential revenue was several times larger. To assure better target survivability, in 2013 the beam current incident on this Ga metal target has been limited to only 75 μA, thus reducing yield by 30%. By decreasing peak temperature by an estimated 200^{o}C with the raster, these targets will be able to survive at higher beam current.

The raster implementation will require rapid cycling magnets and power supplies to continuously move the beam spot. Diagnostic devices in the BLIP beam line that enable measuring the actual beam spot profile, both for initial device tuning and commissioning, and for routine monitoring, do not exist but are required. The needed devices include a laser profile monitor, beam position monitor, and a plunging multiwire device. An interlock system to detect raster failure is also essential. If the smaller beam spot were to stop moving target destruction could be rapid. In addition, existing beam current monitors in the beam line have become erratic due to age (41 years) and radiation damage and must be replaced. Beam intensity on target is critical information for the production program to predict radioisotope quantity, and for research projects to measure nuclear reaction cross sections of desired radioisotopes.

Return on investment

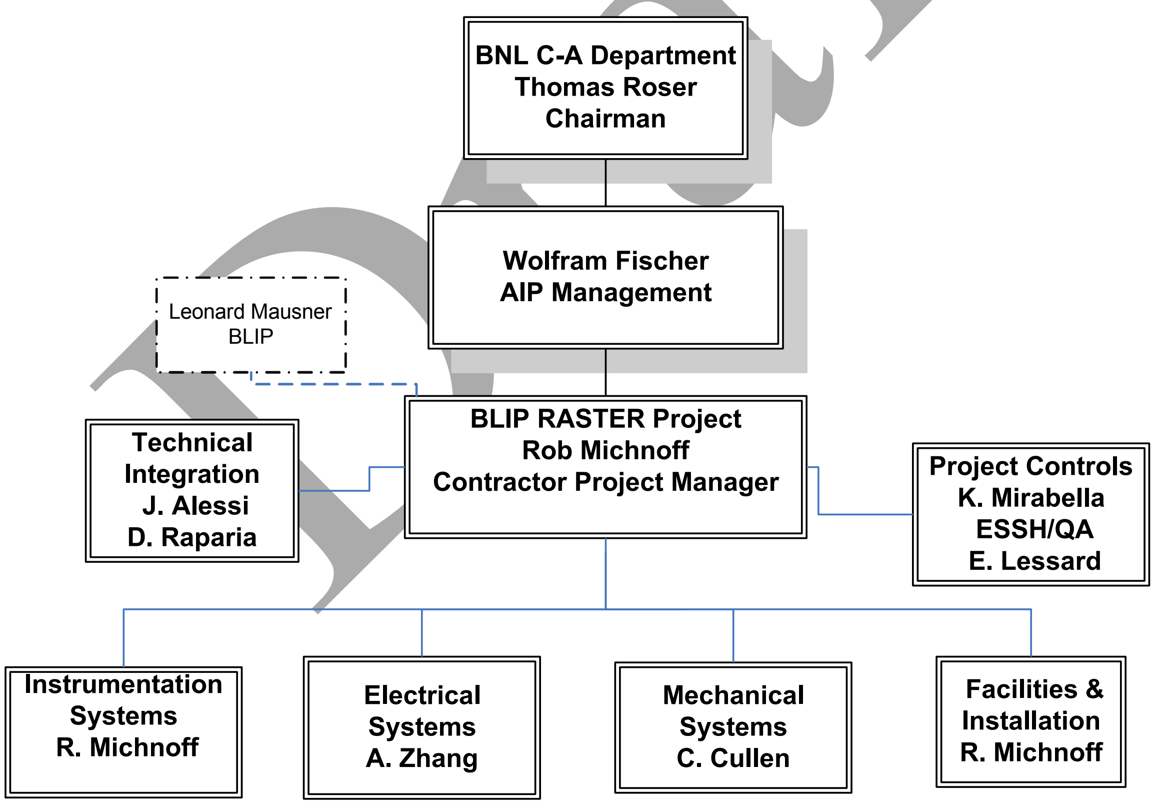
In 2012 and 2013 each year two batches of Sr-82 were lost due to target failure, representing a fabrication replacement cost of $32K. In addition since these targets failed after days or weeks in beam, there is the cost of the wasted beam time, approximately $50-100K per run or up to $200K per year and potential lost sales revenue of up to $320K. The lost revenue from the multiple Ga target failures is an estimated $225-250K per year. The total estimated BNL isotope revenue to the DOE revolving fund for FY2013 is estimated to be $5.1M. In addition an increase in Sr-82 yield of 20% with the raster represents additional potential revenue of another $700K. Thus preventing target loss, improving target yield, and allowing full Linac intensity on target by implementing the raster then totals approximately $1.57M per year in potential program gain. This equates to a return on investment in three years or less.

Estimated/potential impact on annual operating funds

This topic will be addressed when the Reporting Milestone "Decision on Radiation-hardened vs. periodic replacement" is complete. Until then the only impact to operating funds is the savings due to fewer failed targets, which is included in the ROI calculation above.

Project Management

The BLIP Raster system is funded as an Accelerator Improvement Project. Federal Program Manager for the BLIP Raster system project is Marc Garland and the Contractor Project Manager at BNL is Rob Michnoff. The project organization chart below provides additional detail.



Technical Scope and Deliverables

The project scope is to design, fabricate and install the BLIP Raster system (components listed below.

Raster System components include:

- 2 plunging harps and associated electronics
- 1 raster magnet
- 1 raster magnet power supply and associated electronics
- 1 laser profile monitor and associated electronics
- 1 dual plane beam position monitor and associated electronics
- 2 beam current transformers and associated electronics
- controls equipment
- beam interlock system

Successful completion of the project is defined as:

The Raster System is installed at BLIP and rastering and control of the beam is confirmed by the following key performance parameters:

- Raster Magnet and Power Supply confirm rastering of beam at 5 kHz.

- Multiwire harp system confirms rastering by providing evidence of wide profile when rastering is ON compared to narrow profile when rastering is OFF.

- Beam Interlock system employed to inhibit beam.

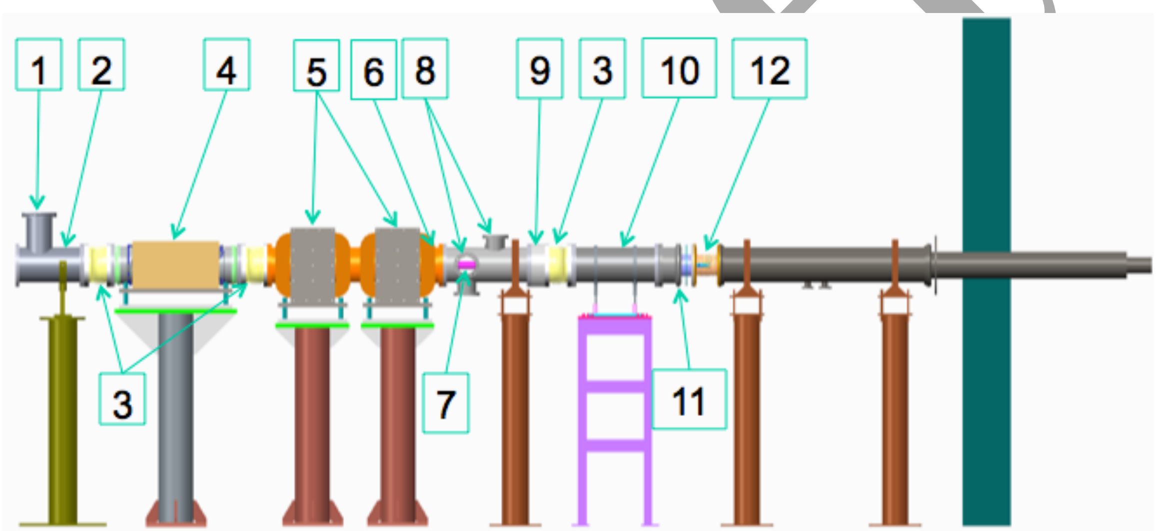
Current expectations for both the short- and long-term performance of individual equipment items are detailed in the tables below.
The following table defines the subsystems that are critical to proving project success. The minimal performance to prove success is identified in the column labeled "Early Performance."

System	Early Performance (Required as part of project completion)	Enhanced Performance
Raster Magnet/Power Supply	Horizontal and vertical magnets/power supplies, 5 kHz sine/cosine signal to provide circular raster, single radius	Raster at 2 different radii to provide improved distribution of beam, radius is constant for each 450 microsecond pulse
Plunging Multiwire	Basic profile data available, plunge and acquire profile on request	Improved integration into control system, including application development if required.
Beam Interlock System	Inhibit LINAC beam if power supply current and magnetic field monitors do not show 5 kHz motion when the beam current transformer indicates that beam is in the BLIP beamline.	Use beam position monitor measurements as additional method for determining that the system is rastering as expected. Inhibit LINAC beam if any signal indicates that the beam is not rastering as expected.
Beam Current Transformer	Continuous current measurements available, signal used for beam interlock	

The following table defines the subsystems that will be provided as part of the BLIP Raster system but are not required to prove project success.

System	Early Performance (Not required as part of project completion)	Enhanced Performance
Laser Profile Monitor	Semi-manual scanning of laser, study operational modes (constant laser position for each 450 microsecond pulse vs. laser sweep during 450 microsecond pulse, etc.)	Automated profile scanning, data delivery and logging to higher level control system; position feedback using profile data
Beam Position Monitor	Limited position data available. Hope to provide at a minimum the position at the beginning and end of each pulse.	Provide many position measurements during each pulse (maybe at 50 kHz rate or faster) to create sufficient plots for monitoring raster motion; incorporate measurements into beam interlock system; develop software application if required.

BLIP Raster system layout



Devices in the new BLIP beam line in order from upstream to downstream.
The length from the upstream start to the existing beryllium window is 152.4” (3.87 m).

1. plunging harp
2. 6.5” collimator
3. bellows (3x)
4. raster magnet
5. steering magnets (2) (existing)
6. 4.0” collimator
7. plunging harp (opposite side)
8. laser profile monitor
9. beam current transformers (2x)
10. beam position monitor
11. beryllium window (existing)

12. bellows (existing)

BLIP Raster Magnet

The raster system contains a steering magnet in the beam line 6 meters upstream of the target station. The steering magnet is constructed with two copper conductor coil assemblies mounted on a single high frequency ferrite core. The two conductor coils permit simultaneous horizontal and vertical beam steering to create the desired circular beam path on the target. The steering magnet is placed external to a ceramic beam tube. A ceramic tube was selected to eliminate eddy current losses and magnetic field distortion.

Two sets of pulse transmission cables will transport the driving pulses from raster pulse generators located in service areas to the raster magnet. A metal enclosure around the raster magnet is required to minimize the electromagnetic interference to surrounding equipment and sensitive instrumentation.

Brookhaven will design and fabricate the coils, magnet, enclosures, and support structures.

BLIP Raster Power Supply

The BLIP Raster power supply will have two identical high voltage solid state pulse generators, their associated gate drives, high voltage charging power supplies, synchronized timing units, essential control, monitoring, and communication subsystems. The power supply equipment will be in a service building away from the high radiation beam line area. Two pulse generators will produce kA of pulse currents with desired amplitude and waveforms to drive the raster magnet coils. The basic current waveform is a two and half cycle sinusoidal wave of 5 kHz frequency with total pulse duration of 450 μs. The pulse repetition rate is 6.67 Hz. Two sets of pulse transmission cables are needed to transport high voltage high current pulses from the generators to the magnet coils. The critical electrical parameters include total system resistance and inductance, which determines the required high voltage level of the pulse generators.

BNL will design, develop, and fabricate a prototype pulse generator and then refine it for production units. We will design their auxiliary subsystems and PLC based control and status monitoring subsystems. All subsystems will be assembled together to form a complete raster power supply system.

Laser Beam-Profile Monitor

The beam profiles need to be monitored in the beam line between the rastering system and the BLIP window. Experience has shown that wire scanners and harps have limited lifetimes in the intense BLIP beam. With the larger average diameter of the beam created by the rastering, wire lifetimes are expected to be longer, however we estimates lifetimes shorter than a single beam run.

Since 2000, BNL has built five beam-profile monitors for H^- beams based on photo-neutralization by Nd:YAG lasers. The H^- ion is a bound state of one proton and two electrons with no excited states. The binding energy of the outer electron is 0.75 eV and an H^- ion can be neutralized by a photon with energy above 0.75 eV (λ < 1.67 mm). Since the detached electron is boosted into an energy continuum, the cross section vs. photon wavelength is a broad curve with a maximum at λ = 930 nm (E_γ = 1.3 eV). Profiles are obtained by scanning a laser beam across the H^- beam and recording the laser-stripped electron current vs. laser position.

All of the current devices use a Q-switched Nd:YAG laser. These lasers are limited to firing a single 10 ns long pulse at repetition rates <20 Hz, which yields only one measurement per linac cycle. A 45° scanning mirror moves between pulses and a profile is built up in 10-50 cycles. If such a device is built for a raster beam system many measurements will be required at each mirror location to average out the beam movement.

For the BLIP application a better approach is to use an Ytterbium pulsed fiber laser such as the Quantel Ylia M20 which has been tested at BNL. These are compact and inexpensive industrial lasers that are built to operate remotely. They are air-cooled and require no maintenance. This laser puts out 20 W at the optimum wavelength for this application in 100 ns pulses at a repetition rate of 20-100 kHz. With this approach, data will be collected continuously over the linac cycle at 10-50 μs intervals. The sum of all the collected pulses at each mirror position will represent the average beam signal at the laser position and the rastering motion will be evident in the modulation of the collected pulses during the linac cycle. This sensitivity to the beam motion is a possible signal for a rastering interlock.

Plunging Multiwire Profile Monitors

Two redundant pairs of semi-destructive plunging multiwires (harps) will be installed at the locations shown in the drawing to measure transverse horizontal and vertical beam profiles at low beam power. Since there is a possibility of damaging the wires due to excessive direct exposure to the beam, the second harp will be available as a backup and switching to the backup will only require moving cables at the device.

A dual headed pneumatic actuator with two 32 x 32 wire harp heads can be provided by Princeton Scientific Corp. and will be mounted to an 8” CF 6-way cross provided by MDC. The design of this beam line device is similar to many others in the Collider-Accelerator department. The 100 μm diameter harp wires are made of a tungsten/rhenium alloy and have a very high melting point. Each harp wire is spring mounted to allow for thermal expansion. The design is such that the wires will always be held straight during the measurement process. Wire heating temperature simulations were done by P. Thieberger using existing and future planned BLIP operating scenarios. The tungsten melting point is not reached, but the temperature excursions are relevant for thermo-mechanical fatigue failures. The expected transverse beam diameter is 5 mm FWHM and 10 mm FW at the base.

Each harp will have long signal cables feeding signal processing electronics in the service building. The electronics will consist of a Euro-chassis that houses eight 8-ch integrator modules. A nearby VME chassis will provide digitizers, timing and a digital I/O interface.

Beam Position Monitor

The purpose of the beam position monitor (BPM) is to measure the horizontal and vertical transverse positions of the beam. One BPM will be installed in the BLIP beam line and will be located downstream of the raster magnet.

A custom BPM will be designed to provide proper matching for the Linac beam parameters in the BLIP beamline - a 450 μs long pulse with repetition rate of 6.67 Hz. Since the beam is expected to be mostly debunched in the BLIP beamline, the 200 MHz RF structure is not expected to be present in the signal.

The electronics used to measure the beam position will also require a custom design. The plan is to process the data for each pulse to provide several position measurements along the 450 μs pulse length, thus providing the capability to measure the position as the beam is rastering. The BPM electronics will use the calculated position data to determine if the beam is rastering as expected, and if not, issue a signal to the beam interlock system to inhibit the beam.

Beam Current Transformers

The AC Current Transformer (ACCT) beam line devices (2) and associated processing electronics and cables will be purchased from Bergoz Instrumentation. Two identical systems will be provided to ensure reliability.

The ACCT is a non-interceptive current transformer. The sensor is built with a single winding, which requires only one wire pair between sensor and electronics; this allows much better EMI rejection when long cables are used. The electronics circuit is multistage, implementing the best low-noise operational amplifier available for this application. The ACCT chosen for the BLIP Raster project consists of an in-flange version of the toroid sensor embedded in a 10" OD CF flange. The in-flange version was chosen to eliminate the need to design a custom mechanical image-bypass shroud and enclosure.

The matched signal processing active electronics circuit is provided in a small box. The full-scale range for ±1 V output can be set for ±100 mA of beam current (BLIP design is 50mA). The system frequency response (-3dB) is from <5 Hz to 200 kHz and the rms noise is specified at 5 mV pp. The cable from toroid sensor to electronics box can be up to 100 m long; this enables the electronics to be mounted outside the beam line enclosure. The measured current signal will be digitized by a scope or VME digitizer and available remotely via the Controls system. A ten turn calibration winding option will be included; it will be driven by a commercial calibration current source to ensure the accuracy of the measurement.

Beam Interlock System

The purpose of the beam interlock system is to inhibit beam to the BLIP beam line when the beam is not rastering as expected. The beam interlock system is critical because BLIP targets can be destroyed if high intensity beam hits the target in the same spot for the entire pulse length for more than a few consecutive cycles.

Several types of problems can prevent the beam from rastering as expected, including:

1. Raster power supply failure
2. Magnet failure
3. Incorrect function driving power supply
4. Raster power supply trigger not properly timed to beam pulse

Custom electronic hardware will need to be developed to provide the required functionality. Two independent methods will be employed to determine that beam is rastering as expected. The first method is to use the BPM measurement system as described above. The second method involves digitizing and monitoring the raster power supply current and aligning this signal with the beam current transformer signal to confirm that the power supply current is modulating when the beam passes through the magnet. Hardware logic must be used to confirm that the power supply current is varying whenever the current transformer indicates that beam is present.

A third possibility for raster detection is to use a signal from the laser profile monitor. Specific details for this option require additional research and consideration.

A hardware output signal will be generated and connected to the existing Linac beam inhibit system to prevent beam from entering the BLIP line when the raster system is not operating as expected.

Work Breakdown Structure (WBS)

WBS		Description	$k
1.0		**Raster AIP**	
1.1		Management	287
1.2		Construction	2841
	1.2.1	Instrumentation	2150
	1.2.2	Magnet and Vacuum	383
	1.2.3	Power Supplies	307
1.3		Installation	277
1.4		Commissioning	85
1.5		Project Milestones (high level)	0
		Subtotal	3490
		Contingency	884
		Total	4374

Cost and Schedule

The Total Project Cost is estimated at $4.374M in AY dollars, funded by Accelerator Improvement Project (AIP) funds. It is planned that $3.53M is received in FY2014 and $0.844M in FY2015. The estimate includes $884k (25.3%) of project contingency funds.

Subsystem experts for each WBS generated the cost estimates, and it is planned that the same individuals will be the System Lead for the BLIP Raster design, fabrication and installation. Most of the material dollars estimated at this pre-design phase are historical costs, catalog pricing and engineering judgment. Contingency was applied at each task line, and the resulting average contingency is 25.3%, or $884k for the total project.

Project Management of the AIP has been estimated as level of effort. The Contractor Project Manager, Rob Michnoff and Project Controls Manager Kerry Mirabella are each estimated at ~20% of their time. The Project Manager is also the subsystem manager for Raster Instrumentation, and his total time on the project is estimated at 40-50%.

A draft resource-loaded schedule continues to be developed in Microsoft Project and includes subsystem milestones as well as high-level Project milestones. The schedule contains 6 months of float from the planned completion to the Project Complete milestone date. In addition, no labor resources are assumed to be available 100% of the time. As an example, the estimated engineering hours are 6576, which could be accomplished by the 16 engineers identified for the project in less than 3 months if they were assigned fulltime. Instead their scope has been scheduled with lag times and will be accomplished in 39 months (planned completion date).

Funding profile

The funding profile assumes a continuing resolution in FY15; therefore the funds requested for FY14 cover the first 5 quarters of planned costs to avoid impact to project progress.

FY14 - $3530k
FY15 - $ 844k

Cost Profile

The fiscal year cost profile below assumes receipt of funds by October 15, 2013

Raster Cost plan ($K, with contingency applied)						
1QFY14	**2QFY14**	**3QFY14**	**4QFY14**	**FY15**	**FY16**	**Total**
502	1216	1044	329	996	287	4374

Milestones

The chart below shows the draft milestones for reporting purposes. With the exception of the Project Start date, most of the related, internal milestones within the schedule occur months earlier than the dates shown below. There are 6 months of schedule float from the planned completion to the Project Complete Milestone.

DRAFT Reporting Milestones	date
Project Start	Oct 15 2013
Designers assigned to project	1QFY14
Access BLIP Spur	1QFY14
PM trip to LANL	2QFY14
Current Transformers ordered	2QFY14
Design Review & Accelerator Systems Safety Review	3QFY14
Material ordered for Plunging Multiwire Profile monitor	3QFY14
Decision on Rad Hard vs. periodic replacement	4QFY14
Summer/Fall 2014 access to BLIP Tunnel	1QFY15
Current Transformer Installation	1QFY15
Magnet stand fabrication begins	2QFY15
Vacuum Fabrication begins	3QFY15
Vacuum Chamber bakeout	4QFY15
Summer/Fall 2015 access to BLIP Tunnel	1QFY16
Equipment installation	1QFY16
Power Supplies ready for Installation	3QFY16
Summer/Fall 2016 access to BLIP Tunnel	1QFY17
Power supply installation	1QFY17
Accelerator Systems Safety Review (equipment installed)	1QFY17
DOE approval to operate	1QFY17
Confirmation of Rastering	3QFY17
Project complete	3QFY17

Risk

The attached Risk list and mitigations were developed by the system experts and will be revised monthly as needed, once funding is received.